Exploratory Research into the Extended Finite-Element Method

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The finite-element method has become the standard tool of computational mechanics in the national laboratory community. This simulation tool accounts for the vast majority of computational analyses performed in support of LLNL's engineering work; and general-purpose finite-element LLNL physics codes such as DYNA3D and ALE3D represent the pinnacle of simulation-based practice in mechanical engineering.

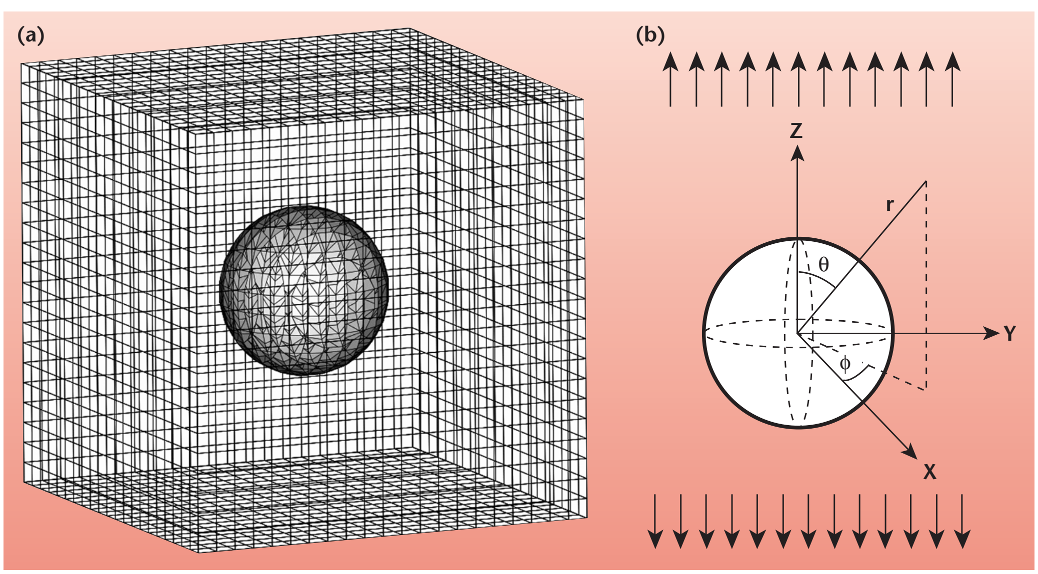
Unfortunately, conventional unstructured finite-element applications are optimized for designing idealized mechanical systems, whereas LLNL missions such as stockpile stewardship are more concerned with analysis of as-built systems. Tools optimized for general mechanical design can, with sufficient effort, provide efficient mechanical analysis of as-built systems. However, discrepancies between idealized and as-built mechanical configurations may be considerable and may, in fact, render analyses based on idealized configurations woefully inadequate.

The goal of this project is to develop extended finite-element (XFEM) techniques by improving conventional finite-element modeling so that the actual configuration of as-built mechanical systems can be subjected to a broader range of mechanics simulations. This XFEM technology will remedy some of the most onerous limitations of finite-element modeling relevant to LLNL needs, such as localization and singular response near cracks and imperfections. This project will substantially extend LLNL's core competence in computational science and engineering and its capabilities in nuclear weapons engineering and manufacturing technologies in support of DOE's national security mission.

During FY02, applied mechanics results achieved in FY01 in the area of crack propagation and material interface were extended to integrate XFEM techniques into computer-aided engineering. In particular, additional capabilities essential for computer-aided problem setup goals—such as automation of mesh generation and material identification—were explored and demonstrated.

Several promising new techniques developed to automate the analysis process include 1) radial basis functions—a new technique for implicit surface definition originally developed for computer graphics rendering—for determining the boundaries of a mechanical system; 2) improved integration techniques for evaluating the governing XFEM equations over regions with irregular material boundaries, cracks, or contact surfaces; and 3) new enrichment functions for modeling voids and other localization phenomena commonly found in materials used in weapons engineering.

Validation of the XFEM techniques included using these new methods to analyze problems with closed-form solutions so that convergence rates can be studied. Figure (a) shows a typical validation problem, in which a spherical inclusion is modeled in an otherwise uniform and isotropic body—represented with a structured XFEM mesh—subjected to uniaxial tension. Figure (b) is the model's boundary-value problem description. Convergence tests demonstrate that both structured and unstructured XFEM solutions converge at the same rate as conventional finite-element methods, which means that these XFEM techniques can be used to construct meshes for analysis with less effort but without compromising accuracy.



Validation of extended finite-element (XFEM) simulation techniques intended to extend the applicability of the finite-element method to as-built mechanical simulations. (a) A spherical inclusion modeled in an otherwise uniform and isotropic body—represented with a structured XFEM mesh—subjected to uniaxial tension. (b) The model's boundary-value problem description, in which arrows indicate the direction of tension.